

ELECTROWEAK RADIATIVE CORRECTIONS TO HADRONIC PRECISION OBSERVABLES AT TEV ENERGIES

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Abstract

We illustrate the impact of full one-loop weak corrections onto b -jet-, prompt-photon- and Z -production at Tevatron and Large Hadron Collider (LHC).

1. WEAK CORRECTIONS AT TEV SCALES

At TeV energy scales, next-to-leading order (NLO) Electro-Weak (EW) effects produce leading corrections of the type $\alpha_{\text{EW}} \log^2(\hat{s}/M_W^2)$, where $\alpha_{\text{EW}} \equiv \alpha_{\text{EM}} \sin^2 \theta_W$, with α_{EM} the Electro-Magnetic coupling constant and θ_W the Weinberg angle. In fact, for large enough \hat{s} values, the centre-of-mass (CM) energy at parton level, such EW effects may be competitive not only with next-to-NLO (NNLO) (as $\alpha_{\text{EW}} \approx \alpha_S^2$) but also with NLO QCD corrections (e.g., for $\sqrt{\hat{s}} = 3$ TeV, $\log^2(\hat{s}/M_W^2) \approx 10$).

These ‘double logs’ are due to a lack of cancellation between virtual and real W -emission in higher order contributions. This is in turn a consequence of the violation of the Bloch-Nordsieck theorem in non-Abelian theories [1]. The problem is in principle present also in QCD. In practice, however, it has no observable consequences, because of the final averaging of the colour degrees of freedom of partons, forced by their confinement into colourless hadrons. This does not occur in the EW case, where the initial state has a non-Abelian charge, as in an initial quark doublet in proton-(anti)proton scattering. Besides, these logarithmic corrections are finite (unlike in QCD), since M_W provides a physical cut-off for W -emission. Hence, for typical experimental resolutions, softly and collinearly emitted weak bosons need not be included in the production cross section and one can restrict oneself to the calculation of weak effects originating from virtual corrections only. By doing so, similar logarithmic effects, $\sim \alpha_{\text{EW}} \log^2(\hat{s}/M_Z^2)$, are generated also by Z -boson corrections. Finally, all these purely weak contributions can be isolated in a gauge-invariant manner from EM effects which therefore may not be included in the calculation. In fact, we have neglected the latter here.

In view of all this, it becomes of crucial importance to assess the quantitative relevance of such weak corrections affecting, in particular, key QCD processes at present and future hadron colliders. We show here results for the case of b -jet-, prompt-photon and Z -production at Tevatron and LHC.

2. CORRECTIONS TO b -JET-PRODUCTION

In Fig. 1 (left and right panels) we show the effects of the full $\mathcal{O}(\alpha_S^2 \alpha_{\text{EW}})$ contributions to the $p\bar{p} \rightarrow b\bar{b}(g)$ and $pp \rightarrow b\bar{b}(g)$ cross sections at Tevatron and LHC, respectively. (For details of the calculation, see Ref. [2].) Results are shown for the total inclusive b -jet production rate as a function of the jet transverse energy. (Tree-level EW and NLO QCD effects are also given for comparison.) At Tevatron, $\mathcal{O}(\alpha_S^2 \alpha_{\text{EW}})$ terms are typically negligible in the inclusive cross section, as the partonic energy available is too small for the mentioned logarithms to be effective. At LHC, the contribution due to such terms grows accordingly to the collider energy, reaching the -2% level at transverse momenta of ≈ 800 GeV.

Next, we study the forward-backward asymmetry at Tevatron, defined as follows:

$$A_{\text{FB}}^b = \frac{\sigma_+[p\bar{p} \rightarrow b\bar{b}(g)] - \sigma_-[p\bar{p} \rightarrow b\bar{b}(g)]}{\sigma_+[p\bar{p} \rightarrow b\bar{b}(g)] + \sigma_-[p\bar{p} \rightarrow b\bar{b}(g)]}, \quad (1)$$

where the subscript $+$ ($-$) identifies events in which the b -jet is produced with polar angle larger(smaller) than 90 degrees respect to one of the two beam directions (hereafter, we use the proton beam as

positive z -axis). The polar angle is defined in the CM frame of the hard partonic scattering. In the center plot of Fig. 1, the solid curve represents the sum of the tree-level contributions, that is, those of order α_S^2 and α_{EW}^2 , whereas the dashed one also includes the higher-order ones $\alpha_S^2\alpha_{EW}$. The effects of the one-loop weak corrections on this observable are rather large, indeed comparable to the effects through order α_S^3 [3]. In absolute terms, the asymmetry is of order -4% at the W, Z resonance (i.e., for $p_T \approx M_W/2, M_Z/2$) and fractions of percent elsewhere, hence it should be measurable after the end of Run 2. We expect even larger effects at LHC, however, some care is here necessary in order to define the observable, which depends on the configuration and efficiency of the experimental apparata (so we do not present the corresponding plot in this instance). The α_S^3 results presented here are from Ref. [4].

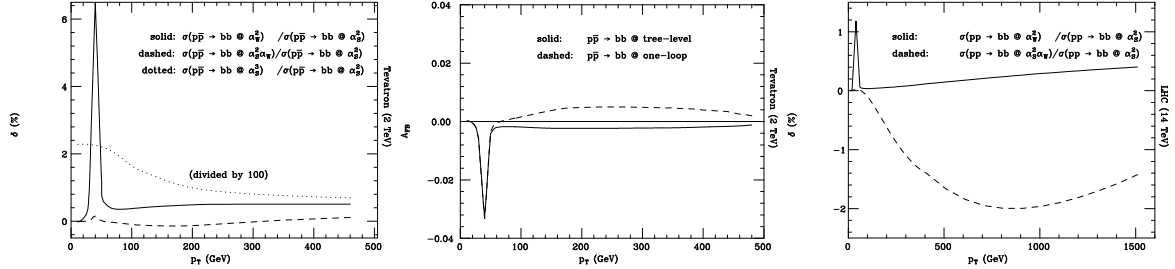


Fig. 1: The corrections (NLO-LO)/LO due to the α_{EW}^2 , $\alpha_S^2\alpha_{EW}$ and α_S^3 terms relative to the α_S^2 ones vs. the transverse momentum of the b -jet for $p\bar{p} \rightarrow b\bar{b}(g)$ and $pp \rightarrow b\bar{b}(g)$ production at Tevatron and LHC, left and right frame, respectively. (For LHC, we do not show the corrections due to α_S^3 terms as results are perturbatively unreliable.) In the middle frame, the forward-backward asymmetry vs. the transverse momentum of the b -jet for $p\bar{p} \rightarrow b\bar{b}(g)$ events at Tevatron, as obtained at tree-level $\mathcal{O}(\alpha_{EW}^2)$ and one-loop $\mathcal{O}(\alpha_S^2\alpha_{EW})$ orders.

3. CORRECTIONS TO γ - AND Z -PRODUCTION

The neutral-current processes ($V = \gamma, Z$)

$$q\bar{q} \rightarrow gV \quad \text{and} \quad q(\bar{q})g \rightarrow q(\bar{q})V \quad (2)$$

are two of the cleanest probes of the partonic content of (anti)protons, in particular of antiquark and gluon densities. In order to measure the latter it is necessary to study the vector boson p_T spectrum. That is, to compute V production in association with a jet (originated by either a quark or a gluon). We briefly report here on the full one-loop results for processes (2) obtained through $\mathcal{O}(\alpha_S\alpha_{EW}^2)$. (For technical details of the calculation, see Ref. [5].)

Fig. 2 shows the effects of the $\mathcal{O}(\alpha_S\alpha_{EW}^2)$ corrections relatively to the $\mathcal{O}(\alpha_S\alpha_{EW})$ Born results (α_{EM} replaces α_{EW} for photons), as well as the absolute magnitude of the latter, as a function of the transverse momentum. The corrections are found to be rather large, both at Tevatron and LHC, particularly for Z -production. In case of the latter, such effects are of order -10% at Tevatron and -15% at LHC for $p_T \approx 500$ GeV. In general, above $p_T \approx 100$ GeV, they tend to (negatively) increase, more or less linearly, with p_T . Such effects are indeed observable at both Tevatron and LHC. For example, at FNAL, for Z -production and decay into electrons and muons with $\text{BR}(Z \rightarrow e, \mu) \approx 6.5\%$, assuming $L = 2 - 20 \text{ fb}^{-1}$ as integrated luminosity, in a window of 10 GeV at $p_T = 100$ GeV, one finds 650–6500 $Z + j$ events through LO, hence a $\delta\sigma/\sigma \approx -1.5\%$ EW NLO correction corresponds to 10–100 fewer events. At CERN, for the same production and decay channel, assuming now $L = 30 \text{ fb}^{-1}$, in a window of 40 GeV at $p_T = 450$ GeV, we expect about 1200 $Z + j$ events from LO, so that a $\delta\sigma/\sigma \approx -12\%$ EW NLO correction corresponds to 140 fewer events. In line with the normalisations seen in the top frames of Fig. 2 and the size of the corrections in the bottom ones, absolute rates for the photon are similar to those for the massive gauge boson while $\mathcal{O}(\alpha_S\alpha_{EW}^2)$ corrections are about a factor of two smaller.

Altogether, these results point to the relevance of one-loop $\mathcal{O}(\alpha_S\alpha_{EW}^2)$ contributions for precision analyses of prompt-photon and neutral Drell-Yan events at both Tevatron and LHC, also recalling that

the residual scale dependence of the known higher order QCD corrections to processes of the type (2) is very small in comparison [6]. Another relevant aspect is that such higher order weak terms introduce parity-violating effects in hadronic observables [7], which can be observed at (polarised) RHIC-Spin [8].

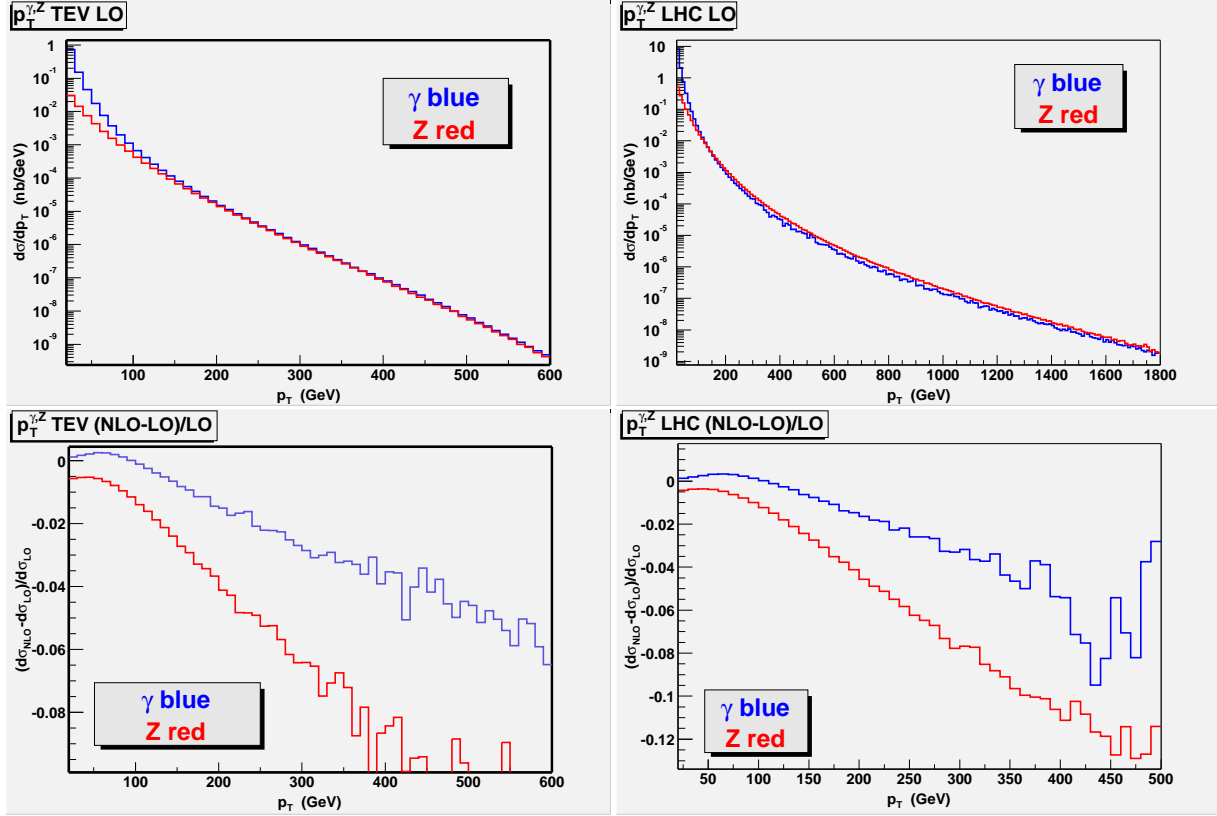


Fig. 2: The LO results through $\mathcal{O}(\alpha_S\alpha_{EW})$ for the γ - and Z-production cross sections at Tevatron and LHC, as a function of the transverse momentum (top) as well as the size of the NLO corrections through $\mathcal{O}(\alpha_S\alpha_{EW}^2)$ relatively to the former.

References

- [1] M. Ciafaloni, P. Ciafaloni and D. Comelli, Phys. Rev. Lett. **84** (2000) 4810 [arXiv:hep-ph/0001142].
- [2] E. Maina, S. Moretti, M.R. Nolten and D.A. Ross, Phys. Lett. B **570** (2003) 205 [arXiv:hep-ph/0307021].
- [3] J.H. Kuhn and G. Rodrigo, Phys. Rev. D **59** (1999) 054017 [arXiv:hep-ph/9807420]; Phys. Rev. Lett. **81** (1998) 49 [arXiv:hep-ph/9802268].
- [4] S. Frixione and M.L. Mangano, Nucl. Phys. B **483** (1997) 321 [arXiv:hep-ph/9605270].
- [5] E. Maina, S. Moretti and D.A. Ross, JHEP **0304** (2003) 056 [arXiv:hep-ph/0210015].
- [6] P. Arnold, R.K. Ellis and M.H. Reno, Phys. Rev. D **40** (1989) 912; P.B. Arnold and M.H. Reno, Nucl. Phys. B **319** (1989) 37 [Erratum-ibid. B **330** (1990) 284]; W.T. Giele, E.W.N. Glover and D.A. Kosower, Nucl. Phys. B **403** (1993) 633 [arXiv:hep-ph/9302225]; J. Campbell, R.K. Ellis and D. Rainwater, Phys. Rev. D **68** (2003) 094021 [arXiv:hep-ph/0308195].
- [7] J.R. Ellis, S. Moretti and D.A. Ross, JHEP **0106** (2001) 043 [arXiv:hep-ph/0102340]; E. Maina, S. Moretti, M.R. Nolten and D.A. Ross, in preparation.
- [8] G. Bunce, N. Saito, J. Soffer and W. Vogelsang, Ann. Rev. Nucl. Part. Sci. **50** (2000) 525 [arXiv:hep-ph/0007218].